Temporal changes in the concentrations of zinc and cadmium in the sedimentary strata of Nozha Hydrodrome, Alexandria, Egypt

doi:10.5697/oc.53-4.993
OCEANOLOGIA, 53 (4), 2011.
pp. 993–1004.

KEYWORDS
Metals
Core sediment
Enclosed pond
Temporal change

Ahmed E. Rifaat*
Hoda H.H. Ahdy

National Institute of Oceanography
and Fisheries (NIOF),
Al Anfushi 21556, Alexandria, Egypt;

e-mail: aerifaat@yahoo.co.uk, e-mail: threeha1@yahoo.com

*corresponding author

Received 26 July 2011, revised 24 October 2011, accepted 3 November 2011.

Abstract

This study is concerned with the temporal changes in the levels of zinc and cadmium in the sediments of Nozha Hydrodrome during the past 100 years. Seven sediment core samples, covering the study area, were collected from the bottom of the Hydrodrome. A five-step sequential extraction technique was applied to determine the solid phase concentrations of zinc and cadmium. Zinc gives an idea of the quantities of sewage effluents, while cadmium provides an indication of the amounts of agricultural discharges. The vertical distribution curves show that the average total concentrations of zinc in the sediments increased at a rate of 2.5 μg g^{-1} y^{-1} from 1900 to 1950 and at 1.5 μg g^{-1} y^{-1} from 1950 to 1990. Since 1990 the zinc concentration in Nozha Hydrodrome sediments has been decreasing at 1.5 μg g^{-1} y^{-1}. The average total cadmium concentration exhibits a different vertical distribution pattern: it increased at a rate of 0.42 μg g^{-1} y^{-1} from 1900 to 1950, after which it became constant from 1950 to 1970. Since 1970 it has been increasing at 0.53 μg g^{-1} y^{-1}. The ongoing increase in cadmium concentrations in the sediments is due to the increase in agricultural discharges into the Hydrodrome, especially as significant amounts of phosphate fertilizers are used to nourish the soil around the Hydrodrome. The rise in cadmium concentrations since 1900 has been accompanied by a similar increase in zinc concentrations with time resulting from

The complete text of the paper is available at http://www.iopan.gda.pl/oceanologia/

the discharge of untreated sewage into the Hydrodrome. In 1990 a sewerage system and sewage treatment plant came into operation, as a result of which discharges of domestic effluent into the Hydrodrome ceased. Since then the amount of zinc in sediments has been decreasing steadily.

1. Introduction

The levels of heavy metals in sediments reflect the impacts of industrial, agricultural and urban development (Fang et al. 2005). They tend to be trapped in sediments of aquatic environments, and their concentrations in particulate form are much higher than those in dissolved form (Balls 1989, Comber et al. 1995). Although, under certain circumstances, part of the metals accumulated in this way may be subsequently released to the overlying water by either physical disturbance (Boughriet et al. 1992) or diagenesis (Petersen et al. 1995), the majority of the accumulated metals remain in the sedimentary compartment. Therefore, the sediment strata at the bottom of an aquatic environment represent a time record (pollution history book) of human activities in that area.

Studies of heavy metals in the environment are important for two main reasons: public health and environment. In the former, attention is drawn to the necessity of measuring the accumulation of heavy metals, particularly those which pose serious health hazards to humans, such as cadmium. In the latter, the main problem is to prevent biological deterioration and to identify the sources that threaten the ecological equilibrium. In this regard, the more abundant heavy metal zinc may sometimes represent a greater hazard than cadmium (Kinne (ed.) 1984).

The present study is concerned with the temporal variation in the concentrations of two specific heavy metals, zinc and cadmium, since they are strongly influenced by anthropogenic inputs (Scoullos & Constandianos 1996). However, despite their importance, data on metal concentrations in Nozha Hydrodrome, until recently, have been very scarce. To our knowledge, no systematic report has been published on the temporal variation of those metals in Nozha Hydrodrome sediments. The aim of this work, therefore, was to investigate the temporal variation in the concentrations of zinc as an indicator of urban activities and cadmium as an indicator of agricultural activities in the sediments of Nozha Hydrodrome.

2. Study area

Nozha Hydrodrome (latitude 31.193°N, longitude 29.977°E) is located south of Alexandria City (Figure 1). It is an enclosed, nearly circular freshwater body with a surface area of about 5.5 km^2 and an average water depth of 2.1 m. The Hydrodrome water has an average salinity ranging

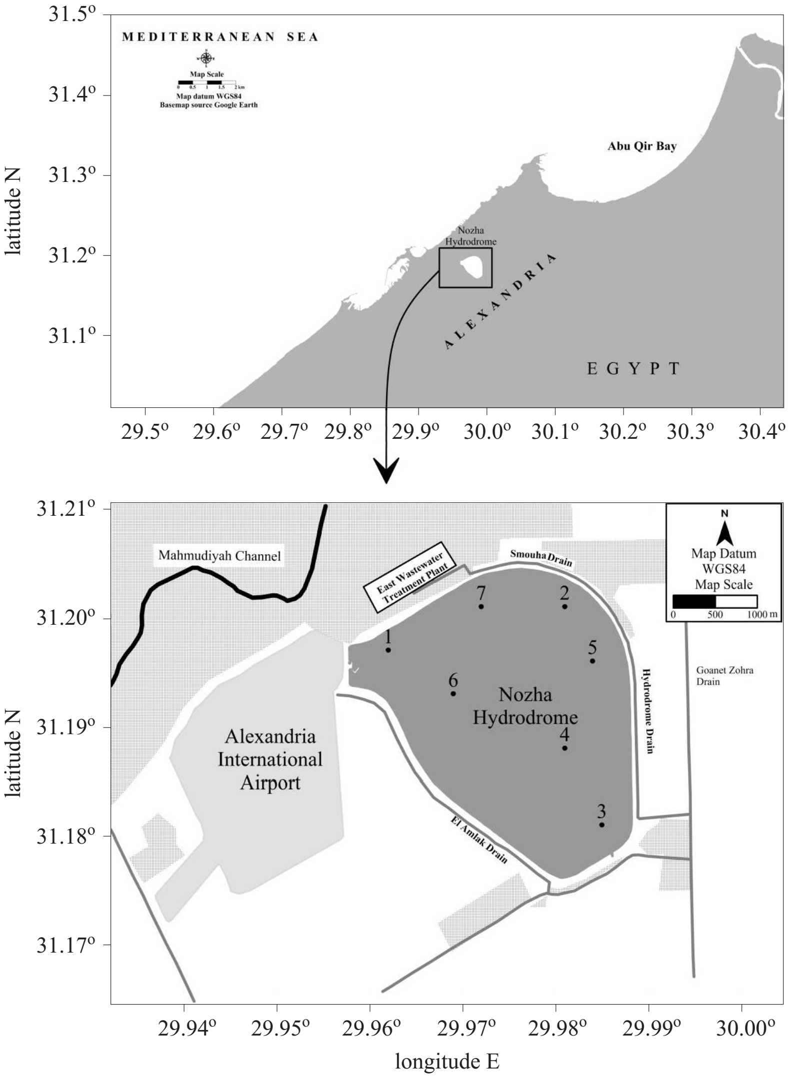

Figure 1. Nozha Hydrodrome and the surrounding features; white areas – cultivated land, crosshatched areas – residential zones, grey lines – drains

between 1.2 and 2.9, and an average pH of 8.9 (Youssef & Masoud 2004). The water temperature fluctuates between 15°C in December and 33°C in August (Ahdy & Saad 2006). It used to be part of Lake Maryut, which received its fresh water from the Mahmoudiyah Channel through a small feeder canal. In 1939, the Hydrodrome was isolated completely from Lake Maryut by a steep-sided concrete embankment. Later the Hydrodrome was used as a fish culture and a duck breeding farm. After the Mahmoudiyah Channel had ceased to flow, the Hydrodrome received its water through several drains that poured untreated domestic and agricultural effluents into the pond (Moustafa et al. 2009). The surplus water of the Hydrodrome is discharged via an outlet located at its south-western limit to the El-Amlak drain that pours into Lake Maryut (Ahdy & Saad 2006).

3. Material and methods

A hand auger equipped with a polyethylene tube was used by SCUBA divers to collect seven sediment core samples, each approximately 75 cm in length, from the bottom of Nozha Hydrodrome (Figure 1). The polyethylene tubes containing the sediments were kept in ice boxes and transferred to the laboratory for analysis. Based on the average sedimentation rate (0.65 cm y^{-1}) in Nozha Hydrodrome (determined by Ahdy (1982) using in situ sedimentary traps) the core samples were split into subsamples, each one representing $\sim$5 years of sedimentation (approximately 3.25 cm). A total of 23 sediment subsamples were obtained for each core. The concentrations of zinc and cadmium in the bulk sediment subsamples were extracted using a technique modified from Tessier et al. (1979), Steinberg & Tayarani-Dastmalian (1993) and Perin et al. (1997). Measurements of zinc and cadmium concentrations were carried out using an Atomic Absorption Spectrophotometer (Perkin Elmer Analyst 800, equipped with Zeman background correction). To ensure the accuracy of these concentrations, the above procedure was conducted 5 times on standard reference material. The recoveries were 90% for Cd and 110% for Zn. The precision of the technique was tested by replicate analysis of the studied metals, using IAEA-SL-1 Standard Reference Material (International Atomic Energy Agency), as shown in Table 1.

Table 1. Replicate analysis for IAEA-SL-1 Standard Reference Material

IAEA-SL-1	Cd = 0.26 [μg^{-1}]	Zn = 223 [μg^{-1}]
run 1	0.31	231
run 2	0.27	228
run 3	0.28	225
run 4	0.25	220
run 5	0.24	235
mean	0.27 ± 0.025	227 ± 5.7
coefficient of variation [%]	9.26	2.51

To test the reliability of the dating calculation using the sedimentation rate, the data on the total concentrations of zinc and cadmium in the sediments in the years 1977 (Ahdy 1982, 1987, El-Rayis & Saad 1990) and

2004 (Ahdy & Saad 2006) were plotted on the vertical distribution curves together with the data of the present study.

4. Results

Because of the homogeneity and similarity of the sediment core lithology, the data of the seven cores have been averaged to obtain an overview of the variation of zinc and cadmium concentrations with time for the entire Hydrodrome.

The average vertical distributions of zinc and cadmium concentrations in the solid phases (exchangeable, bound to carbonate, bound to Fe-Mn oxides, bound to organic matter, and residual) and the average total concentrations in core sediments of Nozha Hydrodrome are presented in Figures 2 and 3 respectively.

Zinc concentrations in the exchangeable and carbonate phases in the sediment core are much lower than those in the other phases, whereas the oxide-phase concentrations are the highest (Figure 2). The zinc

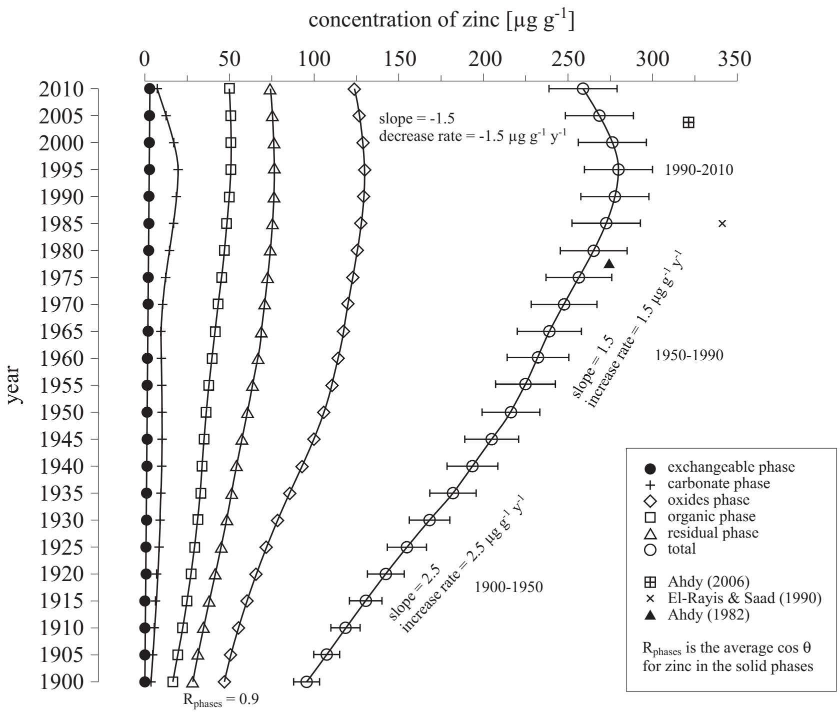

Figure 2. Vertical changes with time in the concentrations of zinc phases in the sediments. R_{phases} is the average $\cos(\theta)$ for zinc in the solid phases (see text for details)

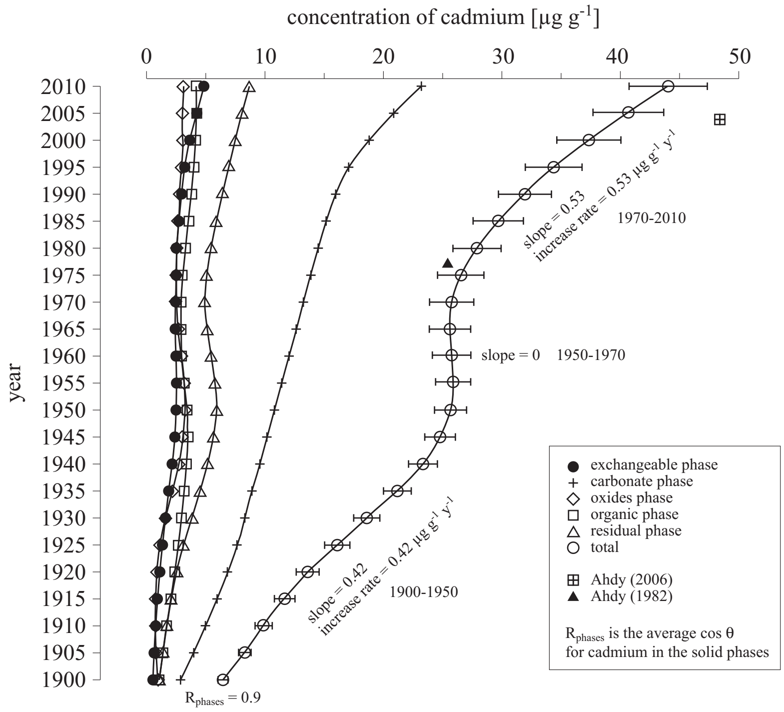

Figure 3. Vertical changes with time in the concentrations of cadmium phases in the sediments. R_{phases} is the average $\cos(\theta)$ for cadmium in the solid phases (see text for details)

concentration in the sediments was at a minimum (96.2 μg g^{-1}) in 1900 and reached a maximum (280 μg g^{-1}) in 1990. The rate of increase in the total zinc concentrations with time was 2.5 μg g^{-1} y^{-1} from 1900 to 1950, decreasing to 1.5 μg g^{-1} y^{-1} from 1950 to 1990. Since 1990 the total zinc concentration has been decreasing at a rate of 1.5 μg g^{-1} y^{-1}, reaching 258.8 μg g^{-1} y^{-1} in 2010.

Cadmium concentrations are higher in the carbonate phase than in the other solid phases (Figure 3). The variation in the total cadmium concentrations (min = 6.5 μg g^{-1} y^{-1} in 1900, max = 43.8 μg g^{-1} y^{-1} in 2010) with time shows a different pattern. The average total cadmium concentration increased at a rate of 0.42 μg g^{-1} y^{-1} from 1900 to 1950, after which there followed a period of approximately no variation (constant concentrations of 26 μg g^{-1} y^{-1}) from 1950 to 1970. After 1970 the average total cadmium concentrations in the sediments increased at a higher rate (0.53 μg g^{-1} y^{-1}) than during the period 1900–1950. The data also show that the vertical distribution curves for both zinc and cadmium follow the same pattern for each metal separately.

5. Discussion

The data on the concentrations of total zinc and cadmium in the surface sediments of Nozha Hydrodrome in 1977 (Ahdy 1982), 1987 (El-Rayis & Saad 1990) and 2004 (Ahdy & Saad 2006) well match those obtained in this study at depths in the sediment cores representing similar years (Figures 2 and 3). This indicates that the technique of dating the Nozha Hydrodrome sediment cores based on the sedimentation rate calculations used in this study is quite reliable. On the other hand, comparison of the average zinc (258 μg g^{-1}) and cadmium (43 μg g^{-1}) concentrations in the upper layer of the sediment cores with those in the surface sediments of the Nile Delta Lakes Maryut (zinc = 508 μg g^{-1}, cadmium = 27 μg g^{-1}) (Saad & Ahdy 2006), Burullus (zinc = 217 μg g^{-1}, cadmium = 5 μg g^{-1}) and Manzala (zinc = 432 μg g^{-1}, cadmium = 84 μg g^{-1}) (Saeed & Shaker 2008) shows that zinc in Nozha sediments is lower than in its mother Lakes Maryut and Manzala, whereas it is slightly higher than in L. Burullus; the cadmium concentration is higher in Nozha sediments than in Lakes Maryut and Burullus but lower than in L. Manzala. These variations in the concentrations of both zinc and cadmium in the surface sediments of the Nile Delta lakes indicate their dependence on the source that supplies both metals to them.

The history of zinc and cadmium concentrations in the sediments of Nozha Hydrodrome shows that there was an increase in zinc from 1900 to 1990 followed by a decrease from 1990 to 2010. On the other hand, since 1900 cadmium concentrations in the sediments have been rising continuously. The zinc concentration in the natural sediments of aquatic environments is $\sim$120 μg g^{-1} or less (CEQG 1999, ANZECC & ARMCANZ 2000, WDNR 2003) and any increase over this value points to increased input due to human activities. In 1900 the total concentration of zinc in Nozha Hydrodrome sediments was 96.2 μg g^{-1}. This value is below the level of zinc in natural aquatic sediments, and the Hydrodrome was considered a clean environment. At that time, there were no urban areas around the Hydrodrome and no untreated sewage was dumped into the pond. The higher zinc concentrations were due to the increase in the untreated domestic effluents discharged into the Hydrodrome as a result of the progressive urbanization around it. Two periods can be distinguished: one was from 1900 to 1950, when the annual rate of increase in total zinc in the sediments was 2.5 μg g^{-1} y^{-1}, and the other from 1950 to 1990, when the annual rate of increase of zinc in the sediments fell to 1.5 μg g^{-1} y^{-1}. Several authors relate the elevated zinc concentration in sediments to anthropogenic discharges to the aquatic environment (Zhu et al. 2001, Taylor & Kesterton 2002, Bi 2003, Dassenakis et al. 2003, Wu et al. 2004, Dong et al. 2004, Yuan et al.

2004, Abd El-Azim & El-Moselhy 2005, Saad & Ahdy 2006, Huang et al. 2007, Luo et al. 2008). As long as Nozha Hydrodrome received untreated sewage from the surrounding urban areas, the rise in zinc concentrations in the sediments reflected the progressive expansion in urbanization with time during the period from 1900 to 1990.

In 1990, the municipality of Alexandria city completed the construction of the Nozha district sewer system and the new East Wastewater Treatment Plant (EWTP) that serves the southern and western districts of the city. After the implementation of the sewer system and sewage treatment plant, much of the discharge of untreated domestic effluents to Nozha Hydrodrome stopped (WWCG 1992). Since then, and despite the ongoing urbanization around the Hydrodrome, the zinc concentration in the sediments has been decreasing at a rate of 1.5 μg g^{-1} y^{-1}.

The point of determining the concentrations of zinc and cadmium in the mobile and residual phases was to assess the stability of the studied metals in the solid phase. The similar vertical distribution patterns (temporal behaviour) for the concentrations of the metals in the different phases indicate that there is a slow or probably no mobilization with time and that the metals tend to be trapped in the solid phase. By contrast, an insignificant relationship indicates mobilization of the metal from the solid to the dissolved phase. To test the potential mobilization from sediment to water the average cosine θ coefficients (R_{phases}) for zinc and cadmium were calculated. This measure represents the relationship between the mobile phases and the residual phase of a metal with time.

The average R_{phases} for zinc concentrations in sediment is 0.9 (Figure 2). This highly significant relationship, together with the environmental conditions prevailing in Nozha Hydrodrome – pH = 8.9 (Youssef & Masoud 2004) and DO = 6.02 mg l^{-1} (Saad & Safty 2004) – suggests that zinc tends to be trapped in the sedimentary compartment. This interpretation could also be inferred from the similarity of the patterns of the vertical distribution curves for zinc in the different phases (Figure 2). Moreover, the average concentration of dissolved zinc in Nozha Hydrodrome water is 8.1 μg l^{-1} (Saad 1987). Comparing the zinc concentration in water with that of natural surface water (10 μg l^{-1}) (Calamari & Naeve (eds.) 1994) indicates that Nozha Hydrodrome water is of good quality and confirms that most of the zinc reaching the Hydrodrome is accumulated and retained in the sediments.

The variation in cadmium concentrations with time in Nozha Hydrodrome sediments exhibits a different pattern. Since 1900 the concentration of cadmium in Nozha Hydrodrome has been high (6.5 μg g^{-1}) as a result of agricultural wastewater discharges into the pond. During the period from 1900 to 1950 the concentration increased at a rate of 0.42 μg g^{-1} y^{-1}.

Between 1950 and 1970 cadmium concentrations apparently did not change, but in 1970 the rate of increase (0.53 μg g^{-1} y^{-1}) became faster than that of 1900–1950. The soil of the cultivated land surrounding the Hydrodrome is fertilized with phosphate and nitrate, and fertilizers produced from phosphate ores constitute a major source of diffuse cadmium pollution (Calamari & Naeve (eds.) 1994). The strong relationship between cadmium and fertilizers has been reported from many areas, e.g. in soil samples collected from Alberta, Manitoba and Saskatchewan, Canada (Lambert et al. 2007). Taylor (1997) mentioned that the increase of cadmium in New Zealand sediment samples is associated with the application of phosphate fertilizers and that over 80% of the Cd added to phosphate fertilizers has remained in the topsoil. The stabilization of cadmium in sediment is enhanced by alkaline pH and high dissolved oxygen concentrations (Thawornchaisit & Polprasert 2009). The cadmium concentration in the water of Nozha Hydrodrome is 0.2 μg l^{-1} (Saad 1987). This value is lower than that of cadmium in natural water ($\sim$1 μg l^{-1}), as reported by Calamari & Naeve (eds.) (1994). The solubility of cadmium in water is influenced to a large degree by its acidity; suspended or sediment-bound cadmium may dissolve when there is an increase in acidity (Ros & Slooff (eds.) 1987). At present, the high pH and dissolved oxygen concentrations of Nozha Hydrodrome water do not permit mobilization of cadmium from the solid to the dissolved phases, so it accumulates with time in the bottom sediments. The calculated R_{phases} for cadmium (0.9) (Figure 3) is a strong indication of the stability of the metal in the sediments. In general, cadmium in aquatic environments is found mainly in the solid phase, i.e. bottom sediments and suspended particles (Nordberg et al. 2007). If the pH of Nozha Hydrodrome water becomes more acidic (lower pH), the trapped zinc and cadmium are likely to be remobilized from the solid phase to the dissolved phase, thereby posing a hazard to the fauna and flora inhabiting the Hydrodrome.

6. Conclusions

Since 1900 zinc and cadmium have been accumulating in the bottom sediments of Nozha Hydrodrome. The temporal variations show that despite the expanding urbanization in the area, zinc in the sediments has been decreasing since 1990: untreated sewage is no longer discharged into the water since the sewer system and wastewater treatment plant came into operation. On the other hand, cadmium concentrations in the sediments have been increasing continuously during the past 100 years as a result of agricultural effluent being discharged into the pond. The reported concentrations of dissolved zinc and cadmium in Nozha Hydrodrome are low when compared with natural levels: this is an indication of the good quality of its water and provides evidence that both metals are trapped in the solid phase (sediment and particulate matter).

Unless major changes in the physicochemical properties (especially pH) of the water take place, cadmium and zinc do not at present pose a serious environmental threat to the Nozha Hydrodrome ecosystem.

References

Abd El-Azim H., El-Moselhy Kh. M., 2005, *Determination and partitioning of metals in sediments along the Suez Canal by sequential extraction*, J. Marine Syst., 56 (3–4), 363–374, doi:10.1016/j.jmarsys.2004.12.001.

Ahdy H. H. H., 1982, *Distribution of heavy metals in Lake Mariut and Nozha Hydrodrome and their accumulation in fish*, M. Sc. thesis, Alex. Univ., Alexandria, 177 pp.

Ahdy H. H. H., Saad M. A. H., 2006, *Heavy metals in the core sediments of Lake Mariut and Nozha Hydrodrome*, Egypt. J. Aqua. Res., 32 (2), 292–307.

ANZECC & ARMCANZ, 2000, *Australian and New Zealand guidelines for fresh and marine water quality*, National Water Quality Management Strategy Paper 4, Vol. 2. Chapt. 8, Sec. 4, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canaberra, 678 pp.

Balls P. W., 1989, *The partition of trace metals between dissolved and particulate phases in European coastal waters. A compilation of field data and comparison with laboratory studies*, Nether. J. Sea Res., 23 (1), 7–14, doi:10.1016/0077-7579(89)90037-9.

Bi C. J., 2003, *Seasonal variation and chemical species distribution of rhizospere heavy metals on tidal flat in Shanghai*, Oceanol. Limnol. Sinica, 34 (2), 194–200.

Boughriet A., Ouddane B., Fisher J. C., Wartel M., Leman G., 1992, *Variability of dissolved Mn and zinc in the Seine estuary and chemical speciation of these metals in suspended matter*, Water Resour., 26 (10), 1359–1378, doi:10.1016/0043-1354(92)90130-V.

Calamari D., Naeve H. (eds.), 1994, *Review of pollution in the African aquatic environment*, CIFA Tech. Paper 25, FAO UN, 118 pp. [http://www.fao.org/docrep/008/v3640e/V3640E00.htm].

CEQG, 1999, *Canadian sediment quality guidelines for the protection of aquatic life*, Canadian Council of Ministers of the Environment, 5 pp.

Comber S. D. W., Gunn A. M., Whalley C., 1995, *Comparison of the partitioning of trace metals in the Humber and Mersey estuaries*, Mar. Poll. Bull., 30 (12), 851–860.

Dassenakis M., Andrianos H., Depiazi G., Konstantas A., Karabela M., Sakellari A., Scoullos M., 2003, *The use of various methods for the study of metal pollution in marine sediments, the case of Euvoikos Gulf, Greece*, Appl. Geochem., 18, 781–794.

Dong D. M., Li H. L., Li Y., Fang C. S., Li X. H., Xu C. Y., 2004, *Distribution of heavy metals in sediments from the Yitong River: Changchun section*, Res. Soil Water Conserv., 11 (1), 96–136.

El-Rayis O. A., Saad M. A. H., 1990, *Heavy metal pollution in lagoon Mariut on the southern coast of the eastern Mediterranean Sea*, J. KAU Mar. Sci., 1, 6–26.

Fang T., Li X. D., Zhang G., 2005, *Acid volatile sulfide and simultaneously extracted metals in the sediment cores of the Pearl River estuary, south China*, Ecotoxicol Environ. Saf., 61 (13), 420–431.

Huang J., Huang R., Jiao J. J., Chen K., 2007, *Speciation and mobility of heavy metals in mud in coastal reclamation areas in Shenzhen, China*, J. Environ. Geol., 53 (1), 221–228, doi:10.1007/s00254-007-0636-7.

Kinne O. (ed.), 1984, *Marine ecology: a comprehensive, integrated treatise on life in oceans and coastal waters*, John Wiley & Sons, Chichester, 618 pp.

Lambert R., Grant C., Sauvé S., 2007, *Cadmium and zinc in soil solution extracts following the application of phosphate fertilizers*, Sci. Total Environ., 378 (3), 293–305.

Luo M., Li J., Cao W., Wang M., 2008, *Study of heavy metal speciation in branch sediments of Poyang Lake*, J. Environ. Sci., 20 (2), 161–166.

Moustafa M., A-Elazeem W., Yousef B., 2009, *Wastewater pollution control in El-Kalaa drain – Alexandria Governorate*, Thirteenth International Water Technology Conference, IWTC, Hurghada, Egypt, 941–950.

Nordberg G. F., Fowler B. A., Nordberg M., Friberg L., 2007, *Handbook on the toxicology of metals*, Elsevier, Amsterdam, 1024 pp.

Perin G., Fabris R., Manente S., Rebello-Wagener A., Hamacher C., Scotto S., 1997, *A Five year study on the heavy metal pollution of Guanabara Bay sediments (Rio de Janeiro, Brazil) and evaluation of the metal bioavailability by means of geochemical speciation*, Water Res., 31 (12), 3017 –3028, doi:10.1016/S0043-1354(97)00171-1.

Petersen W., Wallmann K., Li P. L., Schroeder F., Knauth H. D., 1995, *Exchange of trace elements at the sediment-water interface during early diagenesis processes*, Mar. Freshwater Res., 46 (1), 19–26.

Ros J. P. M., Slooff W. (eds.), 1987, *Integrated criteria document. Cadmium*, Netherlands National Institute for Public Health and the Environment, RIVM Rep. No. 758476004, 373 pp.

Saad M. A. H., 1987, *Limnological studies on the Nozha Hydrodrome, Egypt, with special reference to the problems of pollution*, Sci. Total Environ., 67, 195–214.

Saad M. A. H., Ahdy H. H. H., 2006, *Speciation of heavy metals in Lake Mariut core sediments*, 7th Int. Conf. on Geochemistry, Fac. Sci., Alex. Univ., Alexandria, Egypt, 6–7 Sept. 2006; V. III, 73–86.

Saad M. A. H., Safty A. M., 2004, *Environmental problems in two Egyptian shallow lakes subjected to different leves of pollution*, Eighth International Water Technology Conference, IWTC8 2004, Alexandria, Egypt, 379–391.

Saeed M. S., Shaker I. M., 2008, *Assessment of heavy metals pollution in water and sediments and their effect on Oreochromis niloticus in the northern Delta Lakes, Egypt*, 8th Int. Symp. on Tilapia in Aquaculture, 475–490.

Scoullos M., Constantianos V., 1996, *Assessment of the state of pollution of the Mediterranean Sea by zinc, copper and their compounds*, UNEP/MAP Tech. Rep. Ser. No. 105, 130 pp.

Steinberg C. E. W., Tayarani-Dastmalian T., 1993, *Changes in metal speciation in a sediment core from an acidified Black Forest lake (Wildsee, Germany)*, Water Air Soil Poll., 68 (3–4), 525–537, doi:10.1007/BF00478474.

Taylor M. D., 1997, *Accumulation of cadmium derived from fertilisers in New Zealand soils*, Sci. Total Environ., 208 (1–2), 123–126, doi:10.1016/S0048-9697(97)00273-8.

Taylor M. P., Kesterton R. G. H., 2002, *Heavy metal contamination of an arid river environment: Gruben River, Namibia*, Geomorphology, 42 (3–4), 311–327, doi:10.1016/S0169-555X(01)00093-9.

Tessier A., Campbell P. G. C., Bisson M., 1979, *Sequential extraction procedure for the speciation of particulate trace metals*, Anal. Chem., 51 (7), 844–850, doi:10.1021/ac50043a017.

Thawornchaisit U., Polprasert C., 2009, *Evaluation of phosphate fertilizers for the stabilization of cadmium in highly contaminated soils*, J. Hazard. Mater., 165 (1–3), 1109–1113.

WDNR, 2003, *Consensus-based sediment quality guidelines; Recommendations for use & application*, Wisconsin Dept. Natural Resour., WT-732 2003, 35 pp.

Wu P., Liu C. Q., Ahang G. P., Yang Y. G., 2004, *Chemical forms and ecological risks of heavy metals in river sediment at carbonatite mining area*, Rural Eco-Environ., 20 (3), 28–31.

WWCG, 1992, *Alexandria wastewater masterplan program update*, A report for the Alexandria General Organisation for Sanitary Drainage WWCG in association with WARITH/ECG, 248 pp.

Youssef D. H., Masoud M. S., 2004, *Behavior of some acid-base indicators in some Egyptian aquatic environments*, Bull. Chem. Technol. Macedonia, 23 (1), 37–46.

Yuan C., Shi J., He B., Liu J., Liang L., Jiang G., 2004, *Speciation of heavy metals in marine sediments from the East China Sea by ICP-MS with sequential extraction*, Environ. Int., 30 (6), 769–783, doi:10.1016/j.envint.2004.01.001.

Zhu G. W., Chen Y. X., Zhou G. D., Wang F. P., Wu J. B., 2001, *Distribution of heavy metals in the sediments from the Grand Canal (Hangzhou section)*, China Environ. Sci., 21 (1), 65–69.